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By W. J. SOLLAS, LL.D., D.Sc., F.R.S., and A. McHENRY, M.R.I.A.

(Plate XXX.)

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XIX.

ON A VOLCANIC NECK, OF TERTIARY AGE, IN THE COUNTY OF GALWAY.

By W. J. SOLLAS, LL.D., D.Sc., F.R.S., and A. McHENRY, M.R.I.A.

(Plate XXX.)

[communicated by permission of the director-general of the geological survey.]

(Read June 10, 1895.)

One of the most important features impressed on the structure of our islands in Tertiary times is the great multitude of igneous dykes, some of them of great length, which traverse extensive areas of Scotland, and the north of England and Ireland, with a general direction of from south-east to north-west.

It is doubtful whether even yet the importance of these dykes is sufficiently appreciated, although they have frequently engaged the attention of geologists. Amongst recent writers Professor Judd has alluded to them in connection with that great petrological province, which includes Scotland and Iceland within its boundaries; and Sir Archibald Geikie has more than once described them in impressive language, insisting with appropriate emphasis on the instructive lessons that they teach.

The significance of these dykes is twofold, first as indicating the formation, at some preceding time, of a corresponding number of fissures in the earth's crust, and next in proving the existence of a subterranean reservoir of molten rock, having a distribution co-extensive with that of the dykes themselves.

As regards the fissures they were certainly not faults; as Sir Archibald Geikie points out, "they cross faults of 50 fathoms throw and more, without being deflected"; they were rather open cracks, which by their general parallelism, suggest the operation of a force acting in some definite direction.

During the elevation of the Alpine-Himalayan system of mountain-chains, the whole Europe-Asian continent was subject to a system of stresses, the effects of which are obvious in the south-east of England as a deformation by folding. In the northern and western portions of our area effects of this nature, though they may exist, are certainly not conspicuous; the deformation in this region was of a different kind, and would seem to have manifested itself in the opening of the numerous fissures, which are now occupied by igneous dykes.

The folding of the strata of the south may be explained as the result of long-continued or frequently repeated thrusts, the direction of which, as given by the axes of the folds, was from the south, or south and east; and it is in the same direction, as we have seen, that the fissures under consideration chiefly trend; but this is also the direction, which on mechanical principles they might be expected to take, if they were produced by the same thrusts as those which determined the structure of the southern part of the country.

Further, we have evidence not only that appropriately directed thrusts existed, but that they acted at the right time, for both the folding in the south and the opening of fissures in the north of our islands occurred during the middle of the Tertiary era, that is in the Miocene period.

As to the competency of the thrusts to break open the crust, since we have no direct evidence to offer, it must remain a matter of opinion, but it will readily be conceded that the force which applied to the south of our area succeeded in rolling it up into the London and Hampshire basins, and the great dome of the Weald, could scarcely have been of an inferior order of magnitude to that which led to fissuring in the north.

Recurring to the correlation of the direction of the dykes with that of presumably existing thrusts, we may here refer to the researches of M. Bertrand, who has greatly added to our knowledge of the movements of the earth's crust by showing how intimately these movements are connected with ancient structural features, and particularly with primitive folds, which have persistently preserved, from their origin to recent times, their distinctive characters, so that the movements of any area are always predetermined as to their nature and distribution, on the one hand by

already existing anticlinals, which persist as regions of elevation, and on the other by synclinals which persist as regions of depression. From this it would seem to follow, as a natural inference, that the distribution and direction of the tangential forces to which these movements are due are also constant. If this should be the case we may deduce from the direction of the axes of the ancient folds in the northern portions of our islands, the direction of the thrusts which were operative during the Tertiary era.

On referring to a geological map, it will be seen that, in the north of Ireland, these folds preserve a very regular trend from north-east to south-west, and thus indicate for the thrusts which produced them, and which may have been repeated in Tertiary times, a direction from north-west to south-east; but this, it will also be seen, is the direction taken by the dykes, which cross the folds at right angles.

Comparisons have often been made of late between certain structures presented by glaciers, and others, which occur in the earth's crust; some of these comparisons may be less fanciful than is generally supposed; and we may here add another to the list by pointing out the resemblance between these fissures of the crust and the longitudinal crevasses of a glacier, both as regards character and mode of origin.

A striking feature in the distribution of our Tertiary dykes is their increased development in the vicinity of coast-lines; this may be more apparent than real, owing to the fact that in these regions they are more accessible to observation; but it may also be real as well as apparent, and is susceptible of a ready explanation; for sea-coasts are frequently adjacent to leading lines of fracture in the earth's crust, and the existence of at least one such line of fracture on the west of Scotland and the east of Ireland is suggested by the chain of Tertiary volcanos that extends from Skye on the north, through Mull and Antrim, to the Mourne Mountains on the south. In the neighbourhood of such a fracture the land would give way with unusual facility to pressure, and increased formation of fissures might be predicted.

It is interesting to observe that while the dykes in the interior of our islands are never, so far as we know, associated with volcanic products,

yet near the coast such an association is not uncommon; the volcanos of the Inner Hebrides, of Antrim, and Forkill are well-known instances, and the neck which we are about to describe furnishes a fresh example from Galway. Judging from the connection between the distribution of volcanos and sea-margins which obtains at the present day, and which can so frequently be shown to have existed in the past, we may safely conclude that the waters of the Atlantic Ocean were not far distant from the west of Scotland and the north and west of Ireland during the active existence of the Tertiary volcanos.

We now pass to the consideration of the subterranean reservoir of molten material which underlay the northern part of our islands, and extended thence to Iceland on the north, and for a great but unknown distance southwards. Its existence shows that the lower surface of a considerable tract of country was in contact with a fluid "couche," and this alone must have facilitated the formation of the fissures, which the molten material afterwards filled up. But the molten material evidently existed under great pressure, for it not only rose in the fissures, but in some cases attained a height of 3000 feet above the present sea-level, as in the granite mountains of Mourne.

The pressure thus indicated is very great; a column of molten rock, merely 3000 feet in height, corresponds to a head of water of between 7000 or 8000 feet; and one can hardly refuse to believe that this pressure, acting upwards on the overlying country, must have powerfully assisted the tangential thrusts in the formation of fissures.

With these general remarks we pass to the description of the volcanic core of Bunowen Tower, the most southerly representative of Tertiary igneous intrusions at present certainly known in this country.

A little south-west of Bunowen Castle, seven miles south-west of Clifden, there is a well-marked neck of dolerite breaking up through the hornblendic gneiss and indurating it in a very pronounced manner for a considerable distance all round. This neck makes a prominent feature in the district, rising, as it does, to a height of over 200 feet above the surrounding plain. It is somewhat oblong in shape, the longer axis being north and south, and measures in extent 450 by 300 yards. The dolerite

composing it is black, compact, and amygdaloidal, and weathers spheroidally. No traces of tuff or ash-beds are noticeable. The contact between the dolerite and gneiss is well seen in many places on the south side, along the sea cliffs (*vide* figure, page 741).

The rocks of Bunowen Tower have a singularly fresh appearance, recalling the Tertiary basalts and dolerites of the county of Antrim, rather than the closely adjacent diorites and other ancient rocks of the immediate district. The impression produced by an examination of hand specimens is deepened, rather than dispelled, by a study of thin slices under the microscope.

The most completely crystalline specimen (I. 1254. of the Survey Collection) is a greenish-black rock of medium grain, glistening with numerous cleavage faces of felspar. Its specific gravity, as determined by a Walker's balance, is 2·91. Under the microscope it is seen to consist chiefly of plagioclase felspar and augite, which are present in about equal proportions, together with magnetite, olivine, and patches of residual glass. It is a characteristic olivine dolerite.

The olivine, which is by no means uncommon, occurs in fairly large idiomorphic and hypidiomorphic crystals, clear and colourless when fresh, but frequently passing into ochreous and green serpentinous products where attacked by the weather.

The augite, which has a specific gravity of somewhat above 3·34, is yellowish-brown in colour, and occurs in ophitic intergrowths with the felspar. It is perfectly fresh and unaltered.

The felspar, also quite fresh, is of glassy clearness; it is hypidiomorphic, coarsely banded by repeated twinning on the albite, and other plans, extinguishes at a high angle, and has a specific gravity of 2·71. It is therefore labradorite.

Here and there amongst the crystalline constituents are dispersed patches of glassy substance, containing abundant slender lath-like crystals of felspar, sometimes with forked ends, feather-like crystals, and grains of augite and magnetite. Glass rendered dark by included magnetite also occurs as a core within some of the crystals of felspar.

Two other specimens (I. 1255. I. 1256. of the Survey Collection),

otherwise similar, are distinguished by their highly vesicular character; the vesicles are oval or irregular in form, and of microscopic dimensions up to a diameter of 10 mm., either empty or more or less completely filled with various mineral deposits, chiefly calcite, and a dark brown glassy-looking substance with a resinous lustre, which is found upon examination to agree in all essential respects with the "hullite" described by the late Mr. Hardman,* as occurring in a similar manner in vesicular basalt from the county of Antrim.

An analysis by Mr. Hardman of specimens obtained from the basalt of Carnmoney Hill, near Belfast, gave the results shown in column I., and the results of an analysis by Professor Headle†, of similar material from the basalt of Kinkell in Fifeshire, are given in column II.

	I.	II.	III.
SiO_2	39·44	38·59	35·06
Al_2O_3	10·35	17·34	9·21
Fe_2O_3	20·72	15·97	18·42
FeO	3·70		3·25
MnO	trace	1·56	—
MgO	7·47	8·65	6·65
CaO	4·48	3·94	3·99
K_2O	—	0·67	—
H_2O	13·62	13·28	23·20
	99·78	100·20	99·78

In thin slices the substance is of an ochreous-yellow colour, and is isotropic. Its most remarkable character is its extraordinary low specific gravity, which Mr. Hardman found to be 1·76, a result that I can fully confirm by observations made with a diffusion column of methylene iodide and benzol. In this the powdered substance floats as a dense zone between indices of specific gravity, 1·76 and 1·78. It contains no visible air bubbles, and remains floating at the same level for four or five days together, a sufficient period to ensure the complete permeation of such an exceedingly penetrating fluid as that in which it was suspended.

An experiment which was made to determine the quantity of water

* Proc. Royal Irish Academy, ser. II., vol. iii., p. 161 (1878).

† Trans. Royal Soc. Edinburgh, vol. xxix., p. 89.

present gave as a result 27·4 per cent.; but as the quantity experimented upon amounted only to 0·0278 of a gramme, it is doubtful how far this is trustworthy. So far as it goes it indicates a substance allied rather to chlorophaeite than hullite. On the other hand the specific gravity of the chlorophaeite, first described by Mac Culloch, its discoverer, is as high as 2·02, and other examples are said to have a specific gravity of 2·278. Heddle's analysis of the Kinkell "hullite" appears to confirm that of Hardman of the Carnmoney specimens, but unfortunately Heddle does not give the specific gravity of the material he examined, and thus the confirmation is not so complete as could be desired. In any case it is clear that chlorophaeite and hullite are closely related products.

The appearance and habit are so similar to opal that it seemed possible to explain the properties of this material by regarding it as the product of coagulated colloids, such as silica hydrate, ferric hydrate, and such other hydrates as may be present in it. On treatment with a strong solution of caustic soda, the silica readily dissolved out, and was reprecipitated on acidifying with hydrochloric acid, while the residue, coloured red with ferric hydrate, was found to be easily soluble in hydrochloric acid, and yielded, to qualitative analysis, iron, a little lime, and a good deal of magnesia.

Some experiments were made to determine the specific gravity of certain silica hydrates, and freshly precipitated ferric, alumina, and magnesia hydrates, by a method which had been previously described by one of us. A "diffusion column" of Sonstadt solution, diluted with water, is employed, and the freshly precipitated hydrate, after thorough washing, is introduced into it; the water, mechanically mingled with the hydrate, diffuses out into the Sonstadt solution, and as it does so the hydrate gradually sinks till it rests at that position in the column where the surrounding solution possesses the same specific gravity as itself. This can then be determined by floating indexes. The experiments so far made are preliminary, and it is intended to repeat them, other solutions than that of Sonstadt being employed for the diffusion column. For it was noticed that when hydrates were left standing for a long time, some days, in that solution, a decomposition took place, and red mercury iodide was deposited

within the substance of the hydrate. It was found also that slightly different results were obtained when cadmium-borotungstate solution was used than with mercury potassium iodide. These are facts of great interest, and suggest a very promising line of research, which we cannot at present undertake, and we make mention of them here to point out that the results we have so far obtained are merely provisional, and stand in need of repetition. Coagulated silica, freshly prepared from sodium silicate, was found to possess a specific gravity of 1·76, but after drying spontaneously for some months, the specific gravity rose to 1·83, and on analysis the dried substance was found to contain 12·4 per cent. of water. Alumina hydrate, after prolonged dessication, still contained 43 per cent. of water, and possessed a specific gravity of at least 2·02. Freshly precipitated ferric hydrate has a specific gravity of 2·4, and magnesia hydrate of 2·24. It was found that silica, obtained by the decomposition of silicon fluoride by water, possessed a higher specific gravity than that prepared from sodium silicate.

It is clear from these observations that, assuming the accuracy of Hardman's analysis, the abnormally low specific gravity of "hullite" is not to be explained by regarding it as an impure opal, and the suggestion arises whether it may not, after all, be merely a hydrous glass. A mixture of silica hydrate and alumina hydrate may not give us the low specific gravity required, but a hydrated alumina silicate might possibly do so; and we have merely to turn to the zeolites to find instances of minerals with lower specific gravity than their chemical composition would lead us to expect. Thus a specimen of analcime, having a specific gravity of 2·08, afforded to Thomson the following results (column I.) on analysis:—

	I.	II.
SiO_2	48·76	47·46
Al_2O_3	17·44	20·18
CaO	10·47	0·25
K_2O	0·55	4·17
Na_2O	—	9·35
H_2O	21·72	17·65
	98·94	99·06

Gmelinite, with a specific gravity of 2·06, was analysed by Damour, with the results shown in column II.

Even in these cases the specific gravity is still much above 1·76, although the proportion of water is in excess of that found by Hardman in "hullite"; still it must not be overlooked that both the minerals just considered exist in the crystalline state; were it possible to convert them into the state of glass it would probably be found that the transformation would be accompanied by a diminution of specific gravity. Judging from what we know of the behaviour of anhydrous silicates, the specific gravity might fall as much as 12 per cent., so that gmelinite in a glassy state might possibly possess a specific gravity of only 1·84; this, however, is still above that of "hullite," although gmelinite contains a larger proportion of water. It is possible that some error has crept into Hardman's results, affecting either the chemical analysis or the specific gravity. This seems the more probable when the far larger quantity of water found by us in material having a specific gravity of 1·76 is considered.

If we regard "hullite" as simply a hydrous glass of low specific gravity, its occurrence in vesicles, lining their walls and filling them up, will be consistent not only with Mr. Teall's observations on the residual glass in the amygdaloids of the Tynemouth dyke,* but also with the fact that in the Bunowen basalt it occurs not only in the vesicles, but in the substance of the rock as well, forming a genuine glassy base to the other constituents (Plate XXX., fig. 2). At the same time it is worthy of notice that, in the vesicular specimens, characterised by the presence of this peculiar glass, there is an almost entire absence of olivine. Zirkel and others† have speculated on the existence of some connection between such substances as chlorophaeite, or "hullite," and serpentinous decomposition products. It is evident, however, that if any such connection exists in this case the transformation of the olivine must have been completed before the final consolidation of the rock.

With the single exception of olivine the same constituents are present in the vesicular basalt as in the compact dolerite. Under the microscope

* Geol. Mag., vol. vi., p. 481. 1889.

† Lehrbuch der Petrographie, Bd. II., p. 1895. 1894.

they are seen to vary greatly in texture; the felspar, a very fresh and coarsely-banded labradorite, occurs in patches of large crystal grains, ophitically intergrown with augite, and in smaller crystals down to minute slender lath-like forms, which are sometimes seated on a corner of one of the larger crystals, extending radiately from it. Some of the felspar is zonal, and in one instance the core was found to extinguish at an angle of 43°, the margin at 33° only.

The non-crystalline residual portions of the magma are either a green glass or the ochreous-yellow substance known as hullite. It occurs in patches, and most abundantly in the vicinity of the vesicles, which it sometimes entirely surrounds, forming about them a layer, some two millimetres in thickness. It contains numerous grains of magnetite, abundant felspars in long prisms, generally small, slender, and lath-like, sometimes larger, and with an axial core of the glass or hullite as well as augite, which is often plumose, and usually intergrown with felspar. The felspar in these glassy portions of the rock shows a manifest tendency to radiate growth.

Olivine, as previously mentioned, is rarely visible in the vesicular basalt, but, in one or two instances, yellow-coloured serpentine, with included calcite, occur as pseudomorphs after this mineral.

The vesicles are filled partially or completely by calcite, hullite, and green glass; the two latter constituents often presenting a mammillary form with concentric layers of growth. Occasionally a yellow anisotropic substance, with fibrous structure, is associated with the glass; and here and there this fibrous material assumes a chenille-like form, and wanders worm-like through the calcite. In some instances a lath-shaped crystal of felspar may be seen lying inside a vesicle completely immersed in the infilling of calcite.

The resemblance both of the olivine dolerite and the vesicular basalt to the Tertiary dolerites and basalts of the North of Ireland is so definite and precise that we have no hesitation in assigning them to approximately the same period of effusion; and it now only remains to describe an interesting contact product, resulting from the action of the basalt on the gneiss, through which it has been protruded.

In hand specimens, the gneiss, which is of medium fineness, appears to consist of felspar, showing evident cleavage faces, quartz, and a black material running more or less parallel to the planes of foliation. It has a specific gravity of 2·63. Under the microscope, the quartz is seen to form a coarse mosaic with numerous planes of vapour and liquid cavities, which are large and usually irregular in form; it is traversed as well by thin threads of a yellow, apparently isotropic, material; and these commonly pursue an irregular course, sometimes corresponding with the boundaries of the constituent grains of the mosaic, but sometimes not, when they evidently run along cracks; occasionally they take a straight course, filling cracks which run at right angles to the foliation.

The felspar, which was originally orthoclase, and also in all probability albite or oligoclase, has been rendered almost black by richly disseminated opaque dust (a good deal of which consists of minute grains of magnetite); some which appears black by transmitted light is white when seen by reflected light, and probably represents a decomposition product due to weathering. Veins of clearer material, often forming a network, run through the dark felspar, and are evident by contrast.

At the margin of the felspar, where it adjoins the quartz, a layer of yellowish material occurs, like that which has been described as traversing the quartz, and with which it is in continuity. Frequently minute grains of augite are associated with this layer, and may be traced from it into the cracks in the adjacent quartz. These grains or crystals of augite may be present as a single layer only, but in places they form dense aggregations, including grains of magnetite. It then frequently happens that a more than usually rich development of magnetite occurs in the neighbouring felspar, and the felspar may even be reduced to a skeleton crystal, surrounded by magnetite dust. In some instances felspar laths were observed within the clusters of augite crystals, and the total product might then be regarded as a curiously modified quartz andesite formed on a microscopic scale. A good deal of apatite in fairly large crystals occurs within the felspar of the gneiss, usually in close proximity to dense accumulations of magnetite; it contains large vapour cavities, many of which are elongated in the direction of the axis of the prism. This

abundant development of apatite is due to the interaction of the basalt and the gneiss.

From the preceding description it would appear that the basalt has been injected into the gneiss along planes of foliation, that it was absorbed by the felspar of the gneiss, producing chemical changes, of which the only recognisable effects are the development of apatite and magnetite, that it penetrates cracks in the quartz, where it consolidated partly as glass, partly as augite, and insinuated itself also between the quartz and felspar of the gneiss.

NOTE ADDED IN PRESS.

Since the above was written we have visited Bunowen together, and examined more closely the characters of the igneous rock in the field.

The intrusive character of the dolerite and basalt is very obvious, but there is no sign of the occurrence of tuffs. The whole district has been intensely glaciated, and tuffs, if originally present, might well have been carried away by the ice. In one place we had evidence of a later intrusion of some thin veins of a light gray-coloured granophyre into the basalt.

The dolerite weathers into a loose iron-stained rubble, evidently as the result of a coarse ophitic structure; the kernel of some of the nodules of the rubble, consisting of ophitic augite, in crystals of from a-half to three-quarters of an inch in breadth. Near the junction of the dolerite with the ancient schist, veins of tachylite were observed traversing the weathered material.

Not far from the junction, though sometimes 20 to 30 feet from it, many examples were met with of a vesicular dolerite, having the vesicles filled with a white fibrous zeolite. On examination this proved to have a specific gravity of from 2·2 to 2·3, it gave brilliant sodium coloration in the flame, and left an insoluble residue when dissolved in oxalic acid; some

of it, as shown by microscopic examination, is evidently rhombic, some as evidently oblique, with an extinction angle of 22°; it is therefore a mixture of natrolite and scolezite.

The vesicular rock, where most vesicular was also most coarsely crystalline, and sometimes well-formed crystals of black augite, one-third of an inch or more in length, occurred within the vesicles, immersed in the infilling zeolite. The coarseness of the rock was plainly not due in this instance to a slow rate of cooling, but rather to the presence of the vesicles, which gave room for the crystalline constituents of the rock to assume an unusual size and a completely crystalline form. The whole appearance

forcibly recalled to mind the famous geodes, with their contained crystals, of the Mourne Mountain granite. In several cases the coarsely crystalline and vesicular rock was seen to occur in irregular patches, lying within a fine-grained basalt, which was distinguished by a streaky appearance, the streaks running in lines of flow around the vesicular masses.

On the west side of Bunowen Hill is a little gully, which we followed down to the cliffs next the sea below; and here we found, irregularly dispersed through the basalt, numerous angular fragments of quartzite, which must have been broken from some underlying beds, and carried upwards in the basalt at the time of its intrusion.

In searching for "hullite" we came across a vesicular rock, having the vesicles completely filled with a clear transparent glass, of a uniform bottle-green colour, much resembling olivine. On examining the specimens, which we collected of this rock, some weeks after our return to Dublin, we were surprised to find that the green material had seemingly vanished; as, however, precisely similar blebs, but of a brown or black colour, were noticed, we concluded that the green material had changed its colour, as chlorophæite is known to do on exposure to the air. The transformation must have been very thorough, for, on breaking our specimens open, we failed to find any remains of the green substance. The brown substance is that which we have termed in the body of this Paper "hullite," and though this material, being similarly constituted to chlorophæite, might naturally be expected to change colour in the same way, yet when we recall to mind the large proportion of water which we found in our "hullite," it would appear that chlorophæite would have been a more appropriate designation for it, and this notwithstanding its low specific gravity.

Further, in connexion with our previous remarks, the low specific gravity ceases to be in any way remarkable; but if our chlorophæite, with 27 per cent. of water, possesses a specific gravity of 1·76, how comes it that Mr. Hardman's "hullite," with only half as much water, possesses the same specific gravity? It is clear that the Carnmoney specimens require renewed investigation.

An abstract of this Paper was published in *Nature* of June the 27th, 1895; since then I have received, by the kindness of Prof. Cole, a Paper by him on "hullite."* It contains an interesting *résumé* of the literature of the subject, and describes, quite independently, the occurrence of "hullite" as "a true groundwork to the crystalline constituents" of the rock in which it occurs.

* Proc. Belfast Nat. Field Club, 1894–5, p. 1.

Fig. 1.

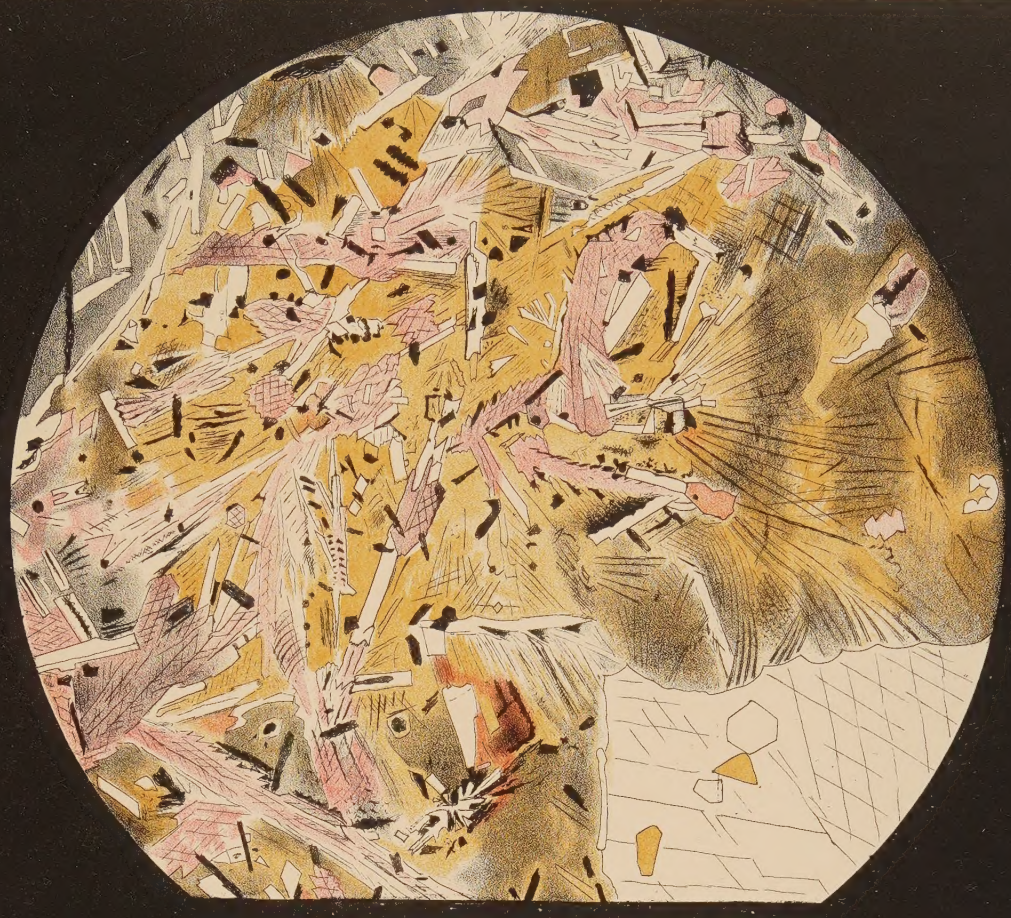

Fig. 2.

West, Newman chromo.